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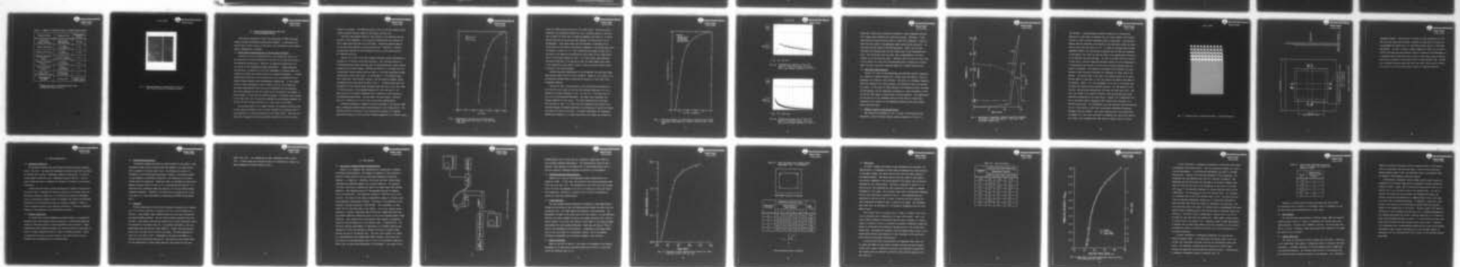

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MINIATURE ACTIVE MATRIX DISPLAY

Final Technical Report for the Period
June 15, 1977 through November 14, 1977

Contract No. DAAK70-77-C-0141

Prepared for

Night Vision Laboratory
Fort Belvoir, Virginia 22060

January, 1978

Rockwell International
Science Center

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by

R. D. Ketchpel
Principal Investigator

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The objective of this program was the development of fabrication methods for an active matrix, flat panel TV display with a resolution of at least 400 elements per linear inch.

The feasibility of such a high-resolution, solid-state, flat panel screen was demonstrated for the first time using thin film electroluminescence as the display media. A resolution of 500 lines per inch with an active area to total area ratio of greater than 0.7 was achieved. The demonstration display panel consisted of 100×100 active elements. Simulated scanning conditions for line-at-a-time (over)

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

The objective of this program was the development of fabrication methods for an active matrix, flat panel TV display with a resolution of at least 400 elements per linear inch.

The feasibility of such a high-resolution, solid-state, flat panel screen was demonstrated for the first time using thin film electroluminescence as the display media. A resolution of 500 lines per inch with an active area to total area ratio of greater than 0.7 was achieved. The demonstration display panel consisted of 100×100 active elements. Simulated scanning conditions for line-at-a-time addressing yielded a time average brightness of up to 7 ft-L under 1/500 duty cycle excitation. This advance indicates that high-resolution, solid-state, flat panel TV display devices are feasible. Further work is required in order to produce a full 500×500 pixel element display including development of line-at-a-time scanning electronics with the associated interface to the display surface.

1.0 INTRODUCTION

A long-standing goal in display technology has been the achievement of a true flat panel TV display. The television cathode ray tube is a difficult device to replace. Developments in the past five years in the semiconductor industry in terms of LSI components have resulted in systems that are display-limited in terms of size, weight and power requirements, particularly with regard to interfacing with mobile soldiers in the field. At the same time, developments have occurred in display technology that appear to make flat panel television within grasp for special applications. Two alternate approaches in particular appear qualified to yield TV imagery under the severe temperature, shock and vibration conditions required by military applications. Both approaches utilize electroluminescent phosphor as a display media. In one case, a nonlinear electro-optic effect and adequate low-duty-cycle emission is achieved by inserting a matrix of selection and control elements between the video drivers and the display elements. These elements are provided by an extension of conventional semiconductor technology. That is, active devices are produced by geometrically configuring with high precision transistor structures at each of 250,000 intersections within the matrix. The alternate approach depends on achieving a nonlinear electro-optic response and low-duty-cycle brightness response through tailoring of the display material itself rather than relying on high geometric precision. Results reported in the literature indicate that both technologies are near providing a full 500×500 line TV image.[1,2] It would appear that the latter approach in which the desirable electro-optic properties are produced in the material rather than through the use of a complex geometric configuration would be an

order of magnitude less expensive to produce based on yield alone. In addition, the thin film electroluminescence approach in which the emitter is 0.5 microns in thickness is uniquely capable of producing the resolution required for this program.

Figure 1 shows a cross section of the display structure and illustrates the simplicity of the thin film EL device. Etched transparent electrodes of indium oxide are contained on the glass substrate to form the electrode pattern in one direction. Vapor-deposited zinc sulfide-manganese-activated phosphor is sandwiched between two vapor-deposited layers of yttrium oxide (dielectric 1 and 2). The rear aluminum electrode is applied orthogonal to the original indium oxide electrodes to provide the x-y addressing of the emitter elements in the matrix. A unique characteristic of this structure is the ability to selectively address the emitter element within the matrix with negligible visible cross-talk from non-addressed intersections. This is due to the highly nonlinear electro-optic response of the emitter. The nonlinear response, in turn, is due to the nature of electron injection into the ZnS phosphor by a tunnel emission phenomenon. The tunnel emission characteristic is relatively independent of temperature so that a display can be operated over a wide temperature extreme. Based on the result to date, the thin film electroluminescent technology would appear to offer the best potential for solving many of the problems of a high-density, small-area, TV-addressed x-y matrix display for military application.

The purpose of this program was to develop fabrication techniques which can be used to produce miniature, high-density active matrix displays for use with television imagery. The immediate goal was to demonstrate over a limited area of the display surface that this technology was compatible with providing high-resolution, television-quality imagery.

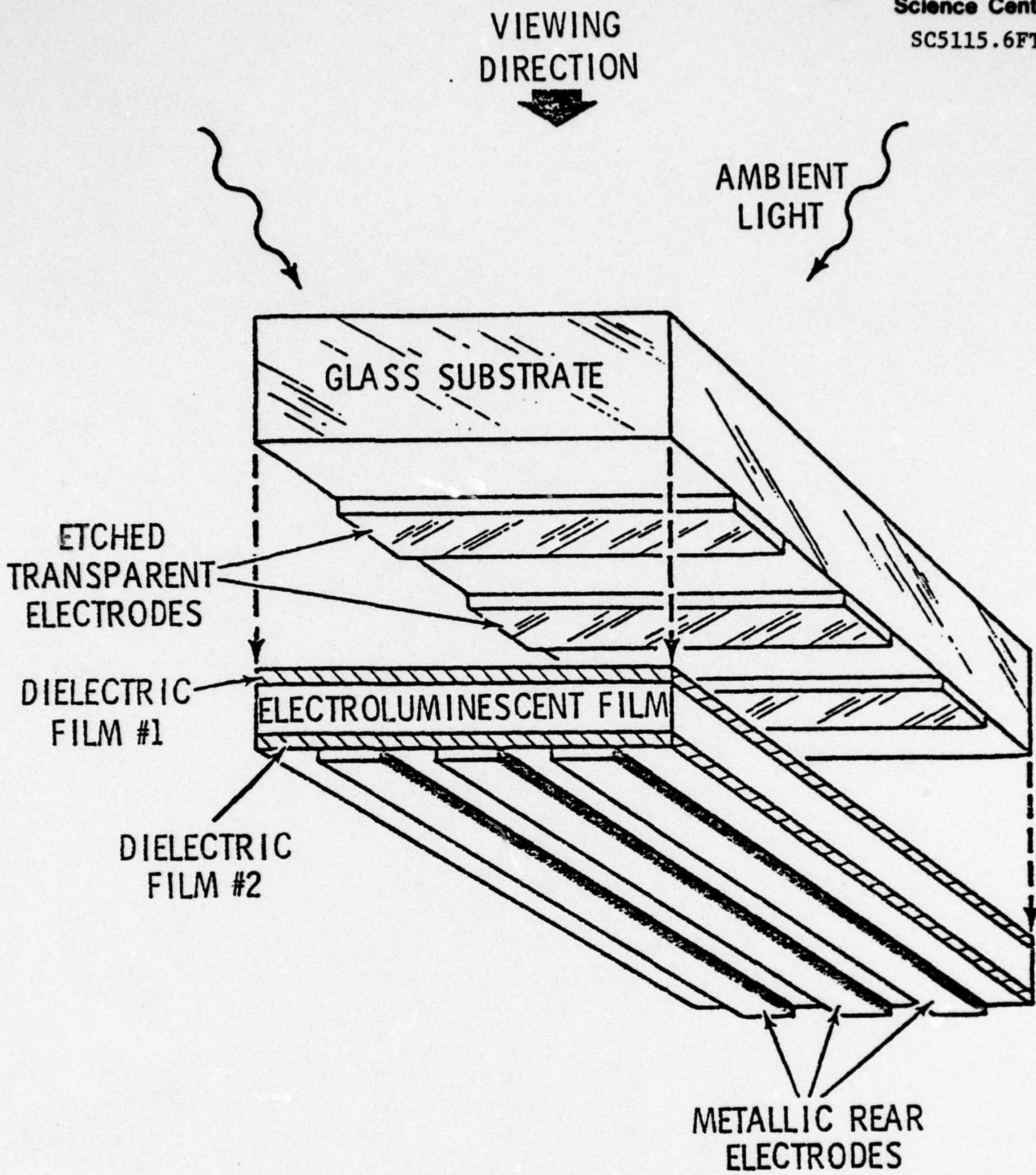


Fig. 1 Matrix address thin film emitter

2.0 PROGRAM OBJECTIVES AND MAJOR ACCOMPLISHMENTS

The objective of this program was to develop fabrication methods for an active high-pixel-density, flat-panel TV display with a resolution of at least 400 and preferably 500 or more pixel elements per inch. A laboratory model with no less than 100×100 pixels was to be evaluated. A major accomplishment was the demonstration of a 100×100 pixel element display at a linear pixel density of 500 lines per inch that had the characteristics required for a television quality display. A table comparing the technical goals of the program with the actual measured results is shown below in Table I. Figure 2 is a photograph of the operating TV matrix display shown at full brightness.

Table I. Summary of Technical Goals and Experimental Results

Characteristic	Technical Goal	Experimental Result
Resolution (Pixel per Inch)	400 ppi min. 500 preferred	500 ppi
Active Area Ratio	0.7 min. 0.8 preferred	0.71
Ambient Reflection	5% max. 1% preferred	4.4%*
Maximum Luminence Range	1-10 ft-L min. 100 ft-L preferred	7 ft-L
Display Uniformity (Macro)	3:1 max. 2:1 preferred	1.16:1
Pixel Uniformity (Micro)	10% max. 5% preferred	4.7%
Gray Scale ($\sqrt{2}$ Change per Step)	8 steps min. 10 preferred	> 8
Time Response (10-90%)	33 msec max.	50 μsec rise 2.9msec decay

*Display operates in reflective rather than transmissive mode (see (5.7)

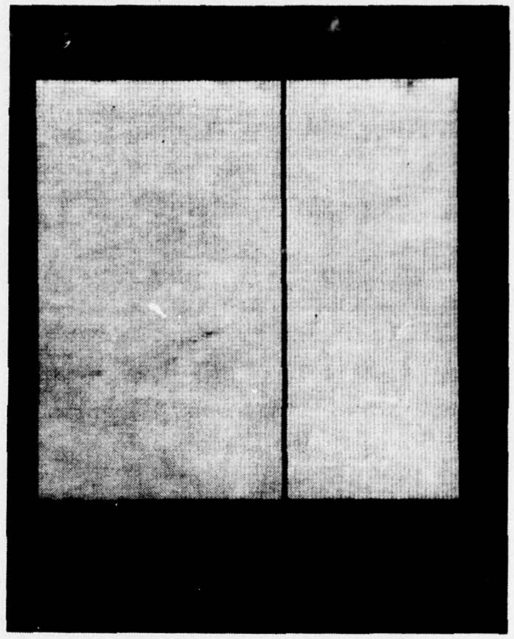


Fig. 2 Photomicrograph of operating 500 line/inch thin film EL display (16X magnification).

3.0 DESIGN CONSIDERATIONS FOR THIN FILM EL ACTIVE MATRIX DISPLAY

This section considers in detail the application of TFEL technology towards solving the miniature active matrix display. In particular, the electro-optic characteristics of the emitter are described and the required device configuration is defined.

3.1 Electro-Optic Characteristics of the Thin Film EL Emitter

Typically, in an x-y addressed matrix, the voltage that exists at a non-addressed electrode intersection is one-half the voltage that exists at the addressed intersections. Therefore, an important characteristic of the emitter is the brightness-voltage relationship. A highly nonlinear characteristic is desirable so that full brightness is produced under full voltage drive while half voltage results in negligible brightness. A further complication arises due to the relative duty cycle of excitation for the desired element compared with non-addressed intersections. If one assumes line-at-a-time addressing for the x-y matrix, that is, all columns are activated simultaneously while one line is addressed then the resultant duty cycle available for any one element is the reciprocal of the number of lines scanned. In the case of a 500-line display, a 0.2% duty cycle results. On the other hand, due to capacitive coupling the non-addressed elements can receive one-half voltage excitation for a duty cycle of near 100%.

The exciting pulse for an element consists of a negative polarity pulse 33 μsec wide as provided by the row driver followed by a positive pulse of equal amplitude, 33 μsec wide provided by the column driver. Note that the selection of negative and positive polarity pulses for the row and column

drivers is arbitrary. The important point is that the row and column drivers produce opposite polarity pulses on the emitter (see Fig. 5a).

The worst case prevails when all rows (lines) in the array but one are excited to full brightness. In this case the non-excited row receives the full column drive pulse 499 out of 500 times. During this period there is no row drive pulse applied to the non-excited row. Therefore, a voltage one-half that required for full brightness results on the non-excited row for 499/500 duty cycle.

Figure 3 is a plot of the time average brightness-voltage characteristic produced by a 0.2% duty cycle pulse excitation. The film was excited by a 66 microsecond-wide pulse occurring every 33 milliseconds which would simulate scanning row-at-a-time through a 500×500 line display at a 30-frame rep rate. A significant feature evident from the figure is the steep brightness-voltage characteristic under pulse drive. If one assumes a 7 ft-L emission under 200 V peak drive, then one-half voltage at the non-selected elements yields a brightness level well below the data in Fig. 3. A separate data point was determined for this emitter while operating under 100% duty cycle, 100 V from a 15 kHz excitation. The brightness measured in this case was 0.1 ft-L which would be the expected brightness due to capacitive cross-coupling at non-addressed intersections. On this basis, one would expect a contrast ratio of 7 divided by 0.1 or 70:1 due to cross talk considerations.

Intensity modulation or shades of gray are provided in the line-at-a-time matrix addressing system by pulse width modulation of the column driver. The composite pulse on the emitter at an intersection consists of a negative going pulse produced by the row driver followed immediately by a positive going

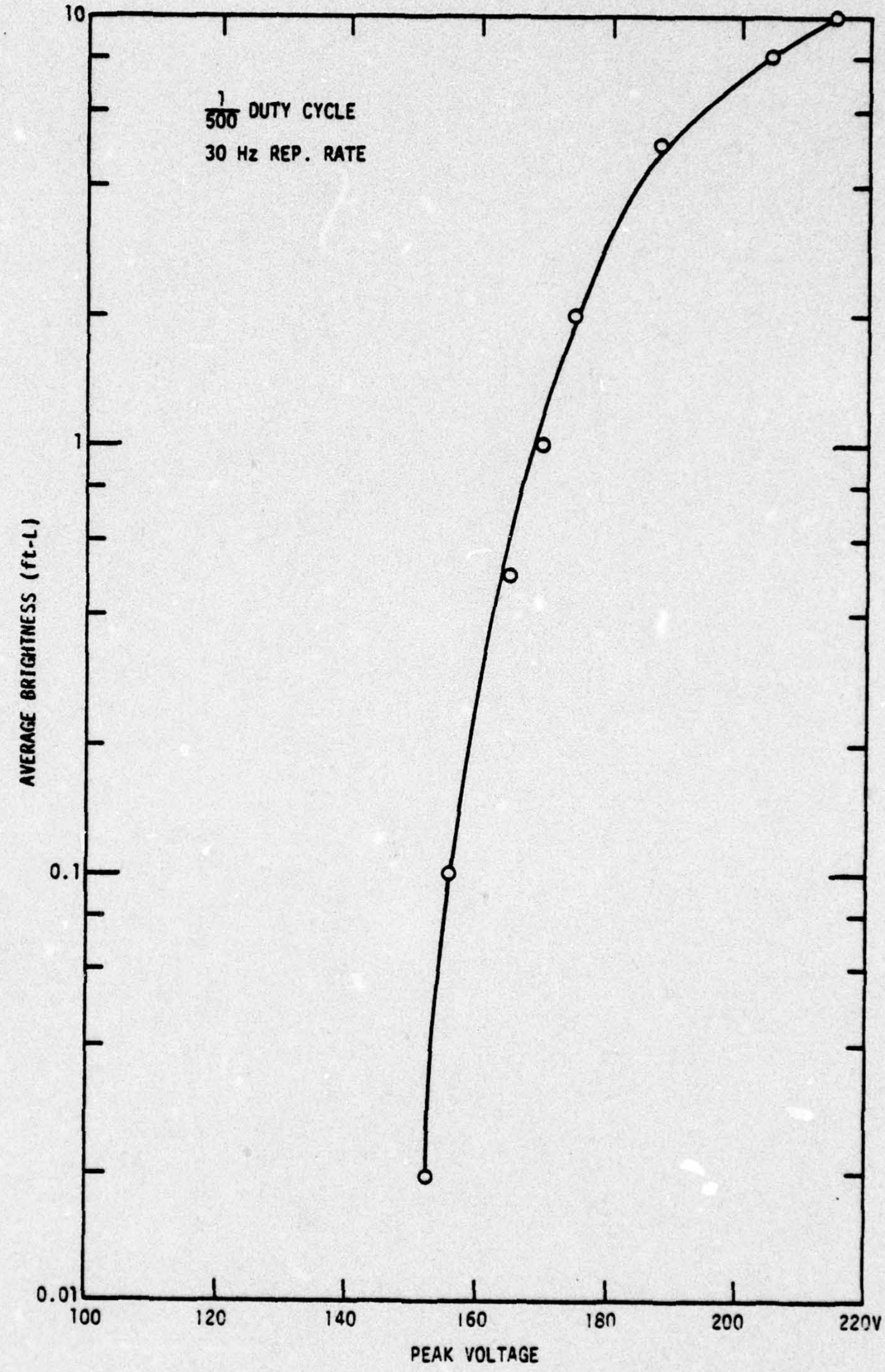


Fig. 3 Brightness vs voltage for thin film emitter under 1/500 duty cycle drive, 30 Hz rep rate, 9 mm^2 area.

pulse of variable width produced by the column driver. The data of Fig. 4 represents the brightness produced for such a composite pulse at 30 Hz rep rate in which the first half or negative component was fixed at a 33 microsecond width and the second positive component was varied from 10 to 35 microseconds. This figure shows that the intensity of emission can be varied 100:1 as the width of the positive component or the column pulse drive is varied by a factor of 3:1. This illustrated how shades of gray can be provided in the display by modulating the pulse width of the column driver when a row-at-a-time address is used. In a video system, some nonlinear correction would have to be applied so that the video signal would result in the appropriate pulse width in order to yield the correct shade of gray contained in the video waveform.

Another important consideration is the brightness rise and decay times when excited under 0.2% duty cycle excitation. Figure 5a is a picture of an oscilloscope waveform which illustrates the build-up or rise time of the brightness waveform.

The data of Fig. 5 were obtained by first adjusting the amplitude of the 0.2% duty cycle pulse so that the time average brightness is 10 ft-L. Therefore, the peak brightness of Fig. 5 is 360 ft-L. The time scale for Fig. 5a is 50 microseconds/centimeter. The upper trace represents the voltage waveform (67 μsec pulse). The lower waveform shows the brightness increase vs time. It is seen that the brightness rises rapidly once the peak voltage is reached--typically, 10 microseconds to reach full brightness after the start of the pulse. In another measurement the brightness waveform was observed for a single pulse after the display has relaxed for

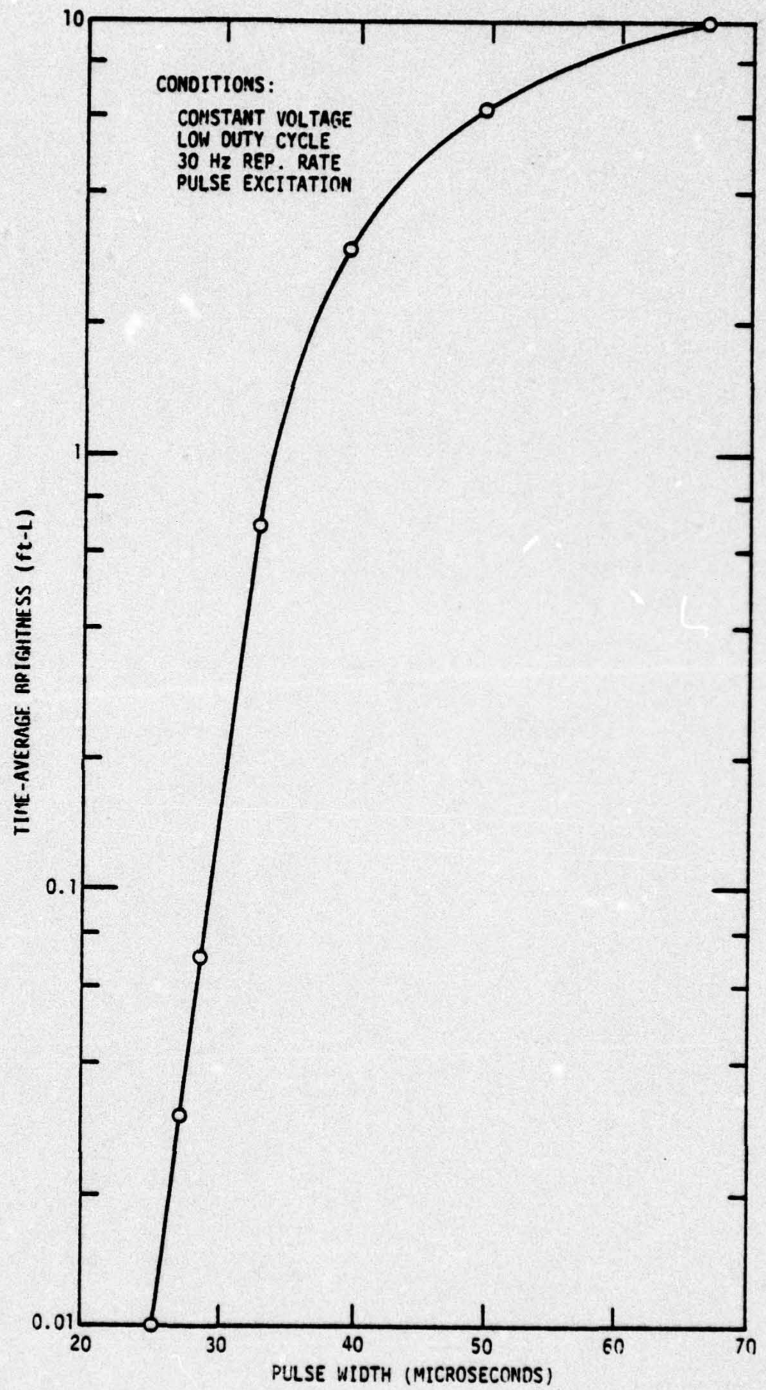


Fig. 4 Average brightness vs pulse width of column driver--1/500 duty cycle, (row driver on 33 μsec), 30 Hz rep rate, 9 mm^2 area.

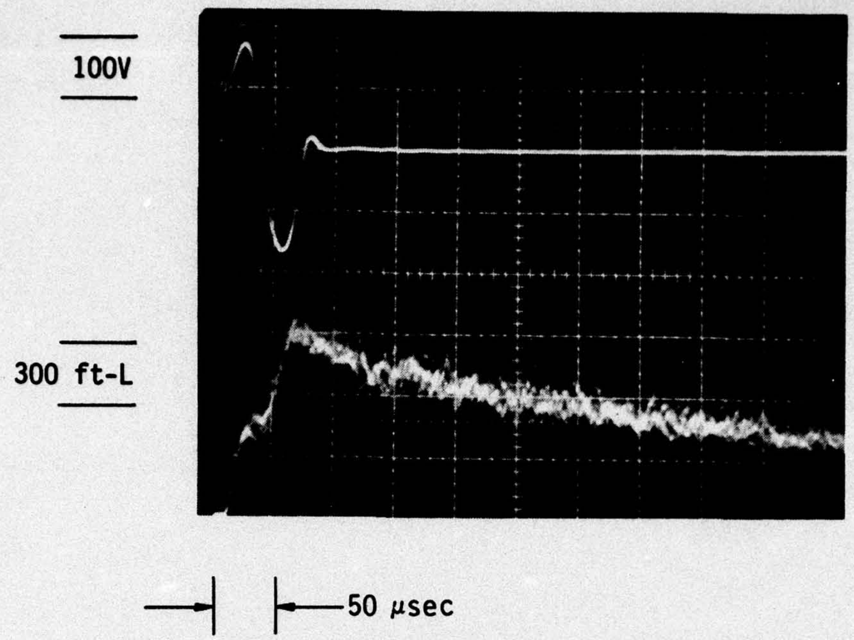


Fig. 5a Instantaneous risetime of thin film emitter - 1/500 duty cycle, 30 Hz rep rate, time average brightness of 10 ft-L.

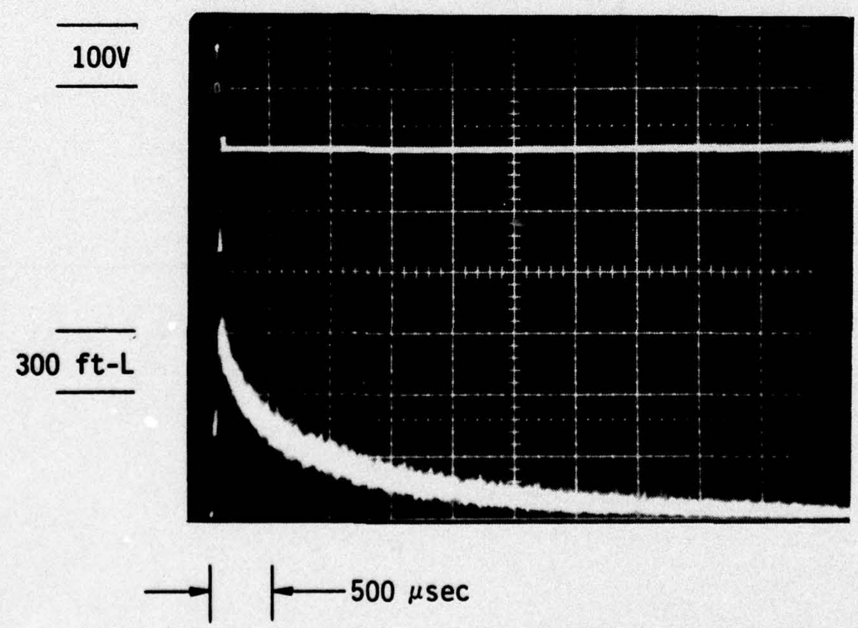


Fig. 5b Instantaneous decay time of thin film emitter - 1/500 duty cycle, 30 Hz rep rate, time average brightness of 10 ft-L.

some time. There was no observable difference in peak brightness obtained for a single pulse compared with repetitive pulsing. Therefore, a video scene does not require multiple scans to obtain full brightness. Figure 5b shows the decay time of the brightness under similar pulse excitation. In this case the time scale is 500 μsec/centimeter. Again, the top trace represents the voltage pulse, and the bottom trace is the brightness waveform. This illustrates that the decay time is approximately 2.9 milliseconds to the 10% intensity level. Therefore, both the rise and decay time of this emitter are less than 30 milliseconds which is adequate to prevent smear and lag in the final television image for a rapidly moving object.

3.2 Electrical Characteristics

Figure 6 is a plot of the capacitance and effective parallel resistance as a function of applied voltage for a typical thin film emitter. Data for brightness vs voltage are also included. The device is a nonlinear capacitor. Below the threshold for visible emission, the dissipation factor is minimum (R_p large). At the onset of light emission, the dissipation factor increases (R_p decreasing), and the capacitance increases to a value equivalent to that of the two oxide layers on either side of the ZnS phosphor. The significance of this data for an x-y addressed matrix is that there is little power dissipated in the emitter at non-addressed intersects where half voltage drive conditions exist.

3.3 Geometric Layout of the Display Device

The resolution requirement for this contract of 500 lines per inch represents a center-to-center spacing between conductors of 0.002", or

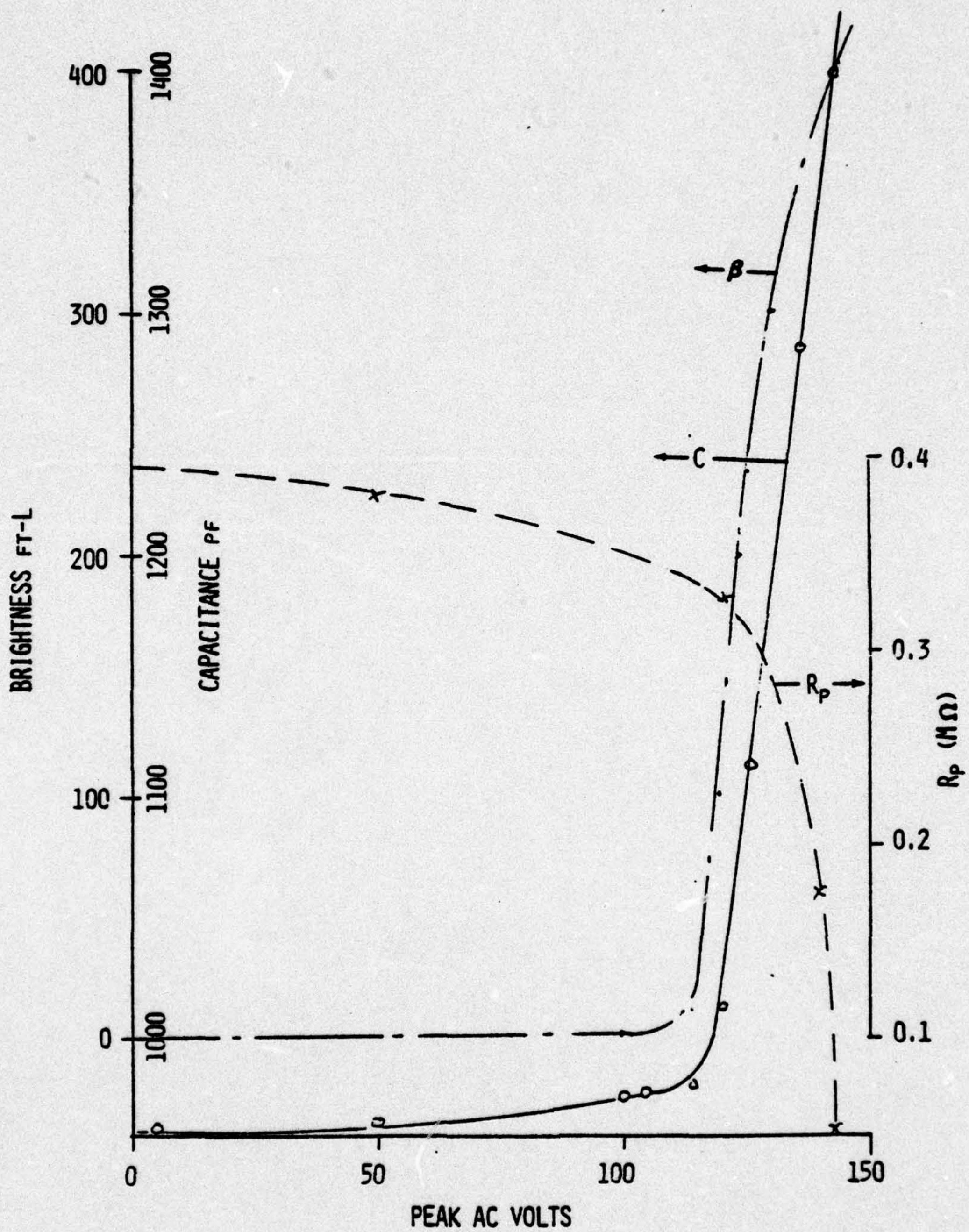


Fig. 6 Capacitance, brightness, effective parallel resistance vs voltage for thin film emitter, 9 mm^2 area, 5 kHz excitation, sample 0525.

50.8 microns. A spacing between parallel conductors of 8 microns was selected as a safe value to maintain over the 1-inch length of the display surface in order to expect reasonable yield in fabrication. The resultant emitter area was therefore 42.8 microns on each side which yields an active area to total cell area ratio of 0.71. In terms of interelectrode voltage breakdown effects, the 8 micron gap is greater than 15 times the thickness of the emitter film itself so that the field is not significantly distorted by the adjacent electrode voltages. In order to provide electrical access to each line, a fan-out scheme was devised in which each line terminated on a 10-mil-square pad located on 20 mil center-to-center spacing along the edge of the display. The conductor electrodes in one direction are interdigited so that alternate electrodes are terminated on either side of the display. The contact pads on one side of the display consist of an array, 50 pads long by 5 pads deep, so that 250 contacts are made on each edge of the display. Figure 7 is a 15X enlargement of one end of the artwork used to define the contact pad and conductor pattern. For the purpose of this contract, the pad array included only 100 lines (50 lines each side). However, the length of the artwork included a one-inch-long span that would simulate the operation of the final device. Figure 8 is a dimensional layout of the device used to demonstrate 500 line-per-inch resolution in a 100×100 active array. For convenience, the final substrate size was selected to be a 2 inch square in order that conventional semiconductor-handling equipment could be utilized. The active substrate area is protected from the ambient by a rear cover slip which is cemented into place after fabrication using a low outgasing epoxy tape material commonly used for hybrid

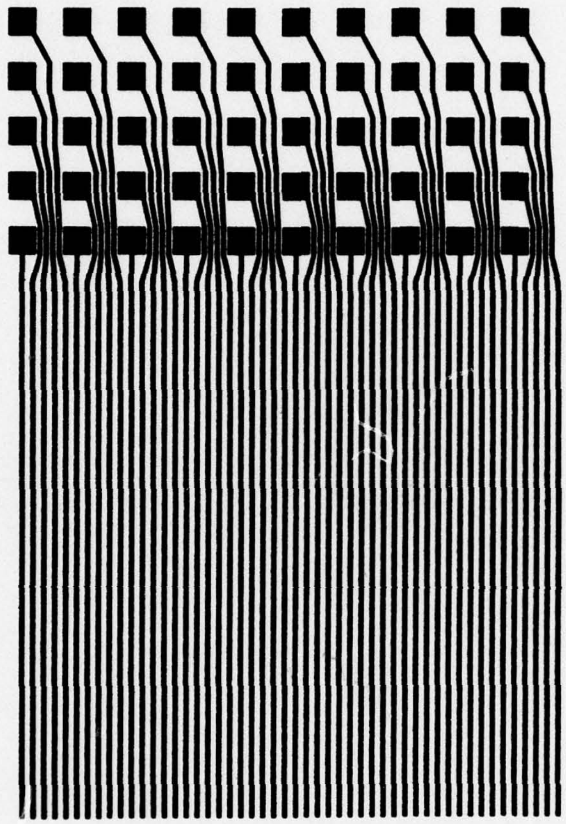


Fig. 7 Miniature matrix electrode artwork - 15X magnification.

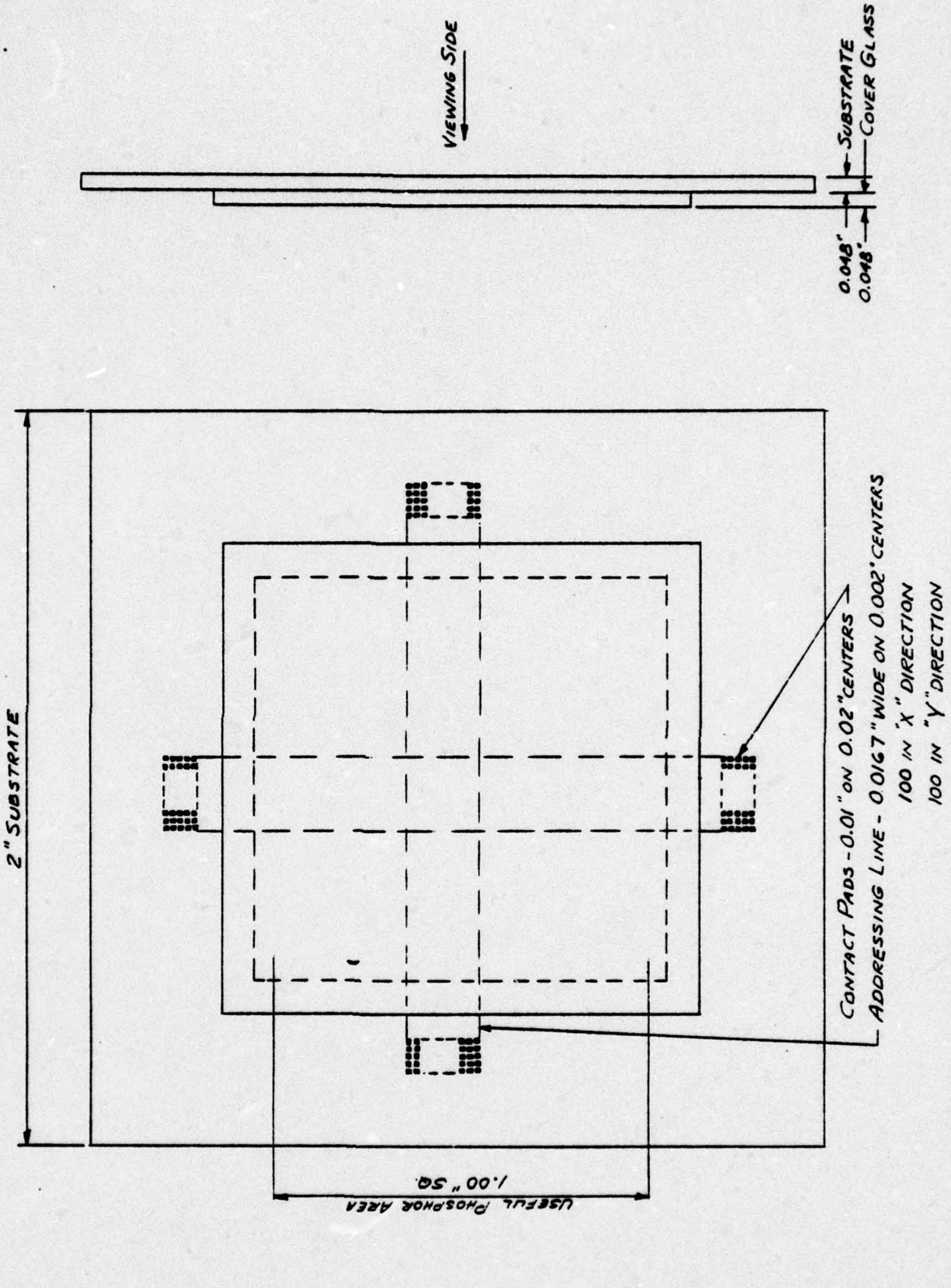


Fig. 8 Layout of test device

packaging purposes. This material is limited in upper temperature to 70°C. The rear cover glass also contains a porthole through which the display is vacuum-pumped and baked prior to a final metal solder seal in a controlled gas ambient. In order to obtain a higher temperature limit for the device (125°C) the epoxy tape seal material could be replaced by the development of a compatible solder glass seal such as used in some liquid crystal displays. The overall thickness of the display device is approximately 2 mm. Through use of thinner substrate glass and rear cover glass, this could be reduced by a factor of 2 in the final device if that is a desirable feature.

4.0 DEVICE FABRICATION

4.1 Substrate Preparation

The substrate material used was Corning 7059 substrate glass, approximately 1 mm thick. The glass was subsequently sputter-coated with two layers of indium oxide to yield a transparent conductor coating with a 5 ohm per square nominal resistivity and a transmission greater than 85%. The two-layer coating was used to minimize the influence of pinholes in the coating resistivity.

Conventional photoresist coating techniques and chemical etching procedures were used to configure the fine-line pattern in the indium oxide film. Meticulous substrate inspection of the indium oxide coating for blemishes prior to photoresist coating as well as stringent dust control and filtering procedures on the photoresist process are necessary elements in order to obtain reasonable yields in the substrate preparation. These are techniques similar to those employed in the semiconductor industry.

4.2 Phosphor Fabrication

The oxide layers and ZnS manganese-activated phosphor are sequentially deposited from a multi-hearth electron beam gun in a high-vacuum evaporator system by techniques similar to those described in the literature.[3] Again, semiconductor-type cleaning procedures and process controls are necessary in order to produce reasonable yields in terms of blemish-free films. During the deposition step the pad contact areas to the indium oxide line are shielded from the deposition by a broad-area mask.

4.3 Top Electrode Fabrication

A broad-area aluminum electrode is finally applied to the device. This electrode is then coated with photoresist and exposed to the same pattern used to generate the indium oxide lines. The aluminum line pattern is orthogonal to the indium oxide line pattern. Finally, the lines are etched in the aluminum by conventional techniques. The simplicity of the whole process should be emphasized. Broad-area films are configured by photolithographic processes similar to that used in the semiconductor industry. No high-definition evaporation masks are required, nor are any tight tolerance alignments necessary. Therefore, the process has the potential for a high yield which is a vital requirement for fabricating a 500×500 active matrix array.

4.4 Packaging

Previous experience with thin film EL emitters has shown that a hermetic seal of the emitter material is necessary in order to avoid degradation by moisture. Other workers report similar effects for both thin film emitters and powder phosphor emitters. For the display devices developed under this contract, a rear glass cover slip was sealed over the emitter material around the periphery of the device (Fig. 8). As previously described, a low outgasing epoxy tape was used as a seal material. A glass cover slip was prepared with a porthole at one corner of the glass. The epoxy material was cured in an air oven at 135°C. Subsequently, the device was baked in a vacuum oven and back-filled with dry air. The device was then sealed under dry box conditions by a metal solder applied to the porthole in the rear

glass cover slip. This package has an upper temperature limit of about 70°C. A solder glass seal system will have to be developed to replace the epoxy component for service limits at 125°C.

5.0 TEST RESULTS

5.1 Test Setup to Measure Display Characteristics

Figure 9 is a schematic that represents the testing setup to measure the display characteristics. The display is mounted in a test fixture in which all contact pads for the top electrodes (aluminum) are gathered together in a common bus. Similarly, the bottom electrode (indium oxide) electrodes are gathered together into a second common bus. The required 0.2% duty cycle pulse is generated by means of an Exact Model 7060 waveform generator. The composite pulse is 67 microseconds wide and is repeated every 33 milliseconds. This simulates scanning at 1/500 duty cycle, 30 Hz rep rate. The output of the pulser is amplified by means of a 30 watt solid state amplifier (Sanyo Model 51-1030G). The output of the amplifier is fed through a coupling transformer (Triad TY19XT). The transformer, in turn, drives the two electrode buses to the display. The optical sensing system consists of a Bausch & Lomb Model AVB-73 which has a Gamma fibre optic eyepiece Model 700-10-37A inserted in place of one of the standard Bausch & Lomb eyepieces. This eyepiece has a 150μ aperture fibre capable of measuring a single 21.4-micron-square cell in the display under 7:1 magnification. For the micro-contrast measurements, an additional 0.01" diameter aperture was inserted 0.2" above the specimen to minimize the effect of emitter light outside the area of the measured spot. The fibre optic eyepiece is coupled to a photomultiplier tube (Gamma Model PM101) through a fibre optic pipe. The output of the photomultiplier tube is fed to an oscilloscope (Tektronix Model 453A) for decay time measurements of the phosphor. The output of the

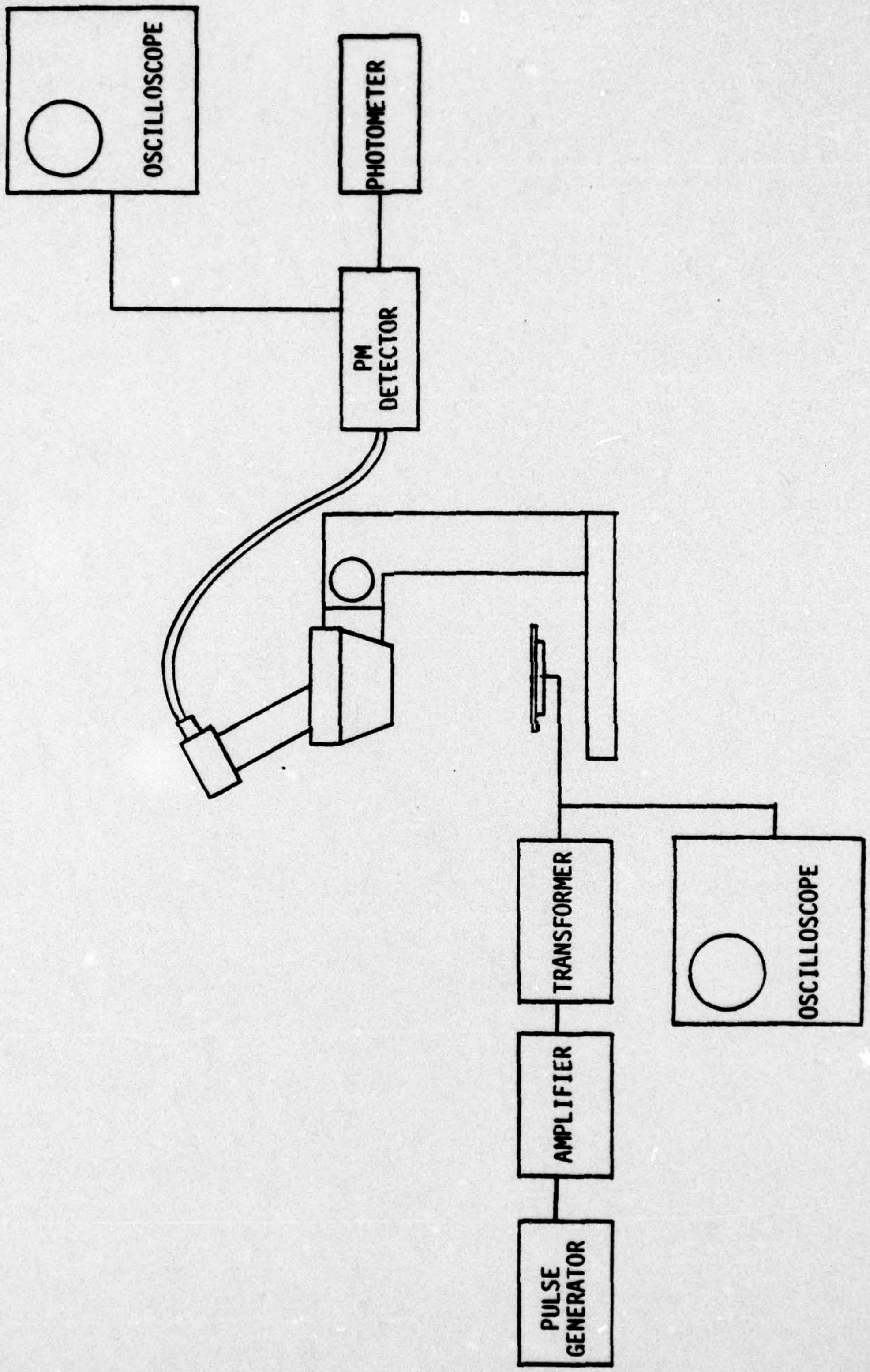


Fig. 9 Electro-optic test setup

photomultiplier tube is also read by a photometer (Gamma Model 2400) for time average brightness measurements. The photomultiplier detector has a photopic filter matched to the sensitivity of the photomultiplier tube so that the resultant brightness readings are directly in foot-Lamberts.

5.2 Brightness-Voltage Characteristics

Figure 10 is a plot of the brightness-voltage characteristics for Sample No. 12087. In this case, the saturated time average brightness under 0.2% cuty cycle was 7 ft-L. The brightness for this cell under half voltage drive, CW drive, was measured to be 0.01 ft-L simulating cross talk brightness conditions. Therefore, a contrast ratio of $>$100:1 is available as limited by cross-talk considerations.

5.3 Pixel Uniformity

The time average display brightness was measured at high magnification through the microscope so that the measuring probe sensed the light from just one emitter cell. The 12087 matrix was operated at full brightness. The measurement was made in the center and at the four corners. At each measuring position, the center element as well as the element directly above, directly below, directly to the left, and directly to the right of that center element was measured for time average brightness. These data are shown in Table II. $\Delta B/B$ is also tabulated for each position. B represents the average brightness for the five points at a particular location. ΔB is the maximum difference in brightness from an adjacent element at that location.

5.4 Display Uniformity

Based on the data of Table II, the ratio of the maximum to the minimum brightness for 25 data points for matrix 12087 was 11.4/9.8 = 1.16 or well within the technical goal of 2:1.

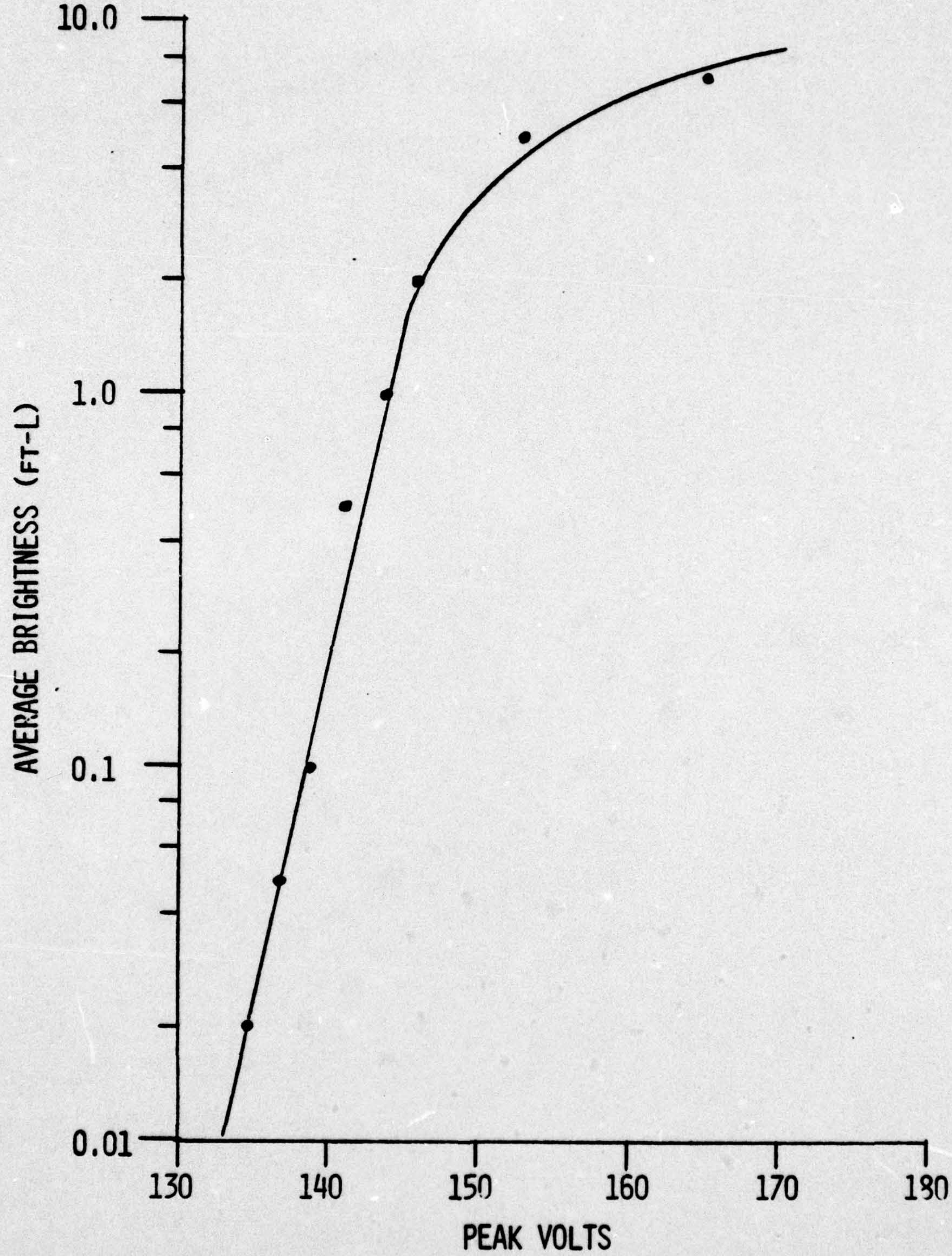
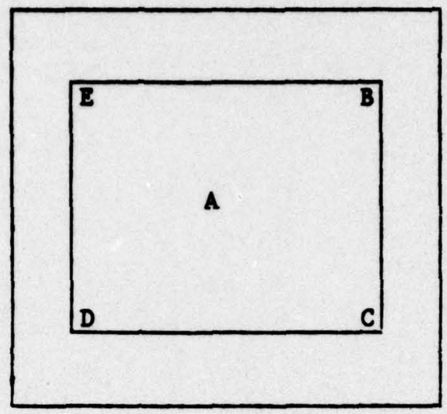


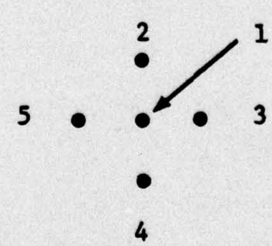
Fig. 10 Brightness-voltage characteristic--Matrix No. 12087, 1/500 duty cycle, 30 Hz rep rate.

Table II. Pixel Uniformity Data--Sample 12087B
Measurement Area: 21.4μ Diameter



Measurement Position on Display

Measurement Position	Brightness--Arbitrary Units: Micro-Location at Each Position					$\left(\frac{\Delta B}{B}\right)_{max}$
	1	2	3	4	5	
A	11	11.1	11.4	11.3	11.4	0.036
B	9.9	9.8	10	10	9.8	0.010
C	10.6	10.3	10.1	10.4	10.2	0.047
D	10.1	10.1	10.1	10.3	10.4	0.030
E	10.5	10.3	10.2	10.1	10.3	0.038



Micro-Location within a Position

5.5 Gray Scale

In order to measure the shades of gray obtainable from the panel, the characteristic of brightness vs pulse width was measured for three locations on the panel; namely, the center and the lower left and right corners of the display surface. The pulse width in this case refers to the width of the positive component of the pulse applied to the display such as would be generated by the column drivers. The data is tabulated in Table III. At each location, the brightness was then normalized with respect to maximum brightness at that point. The resultant pulse width vs normalized brightness for the three locations is plotted in Fig. 11. The brightness data are normalized in the plot of Fig. 11 since in practice the eye utilizes the local variations in shades of gray to construct the image. The equivalent gray scale level is indicated for a $\sqrt{2}$ change in brightness level for each shade of gray.

The ultimate limit on the gray scale or number of shades of gray which can be reproduced can be influenced by at least four factors. First, the electro-optic response of the emitter material must be capable of a linear region of response in order to stimulate intermediate brightness intensities. Figure 11 illustrates this capability through control of the column driver pulse width. Decreasing the intensity from the seventh shade of gray to the eighth shade requires approximately 0.3 μsec decreases in the pulse width which should be achievable electronically.

A second factor which could increase the background light level and so reduce the number of gray shades available has been discussed already: "cross talk" caused by capacitive coupling to non-addressed intersections. The contrast ratio as limited by electrical cross talk was measured to be 70:1 (see 3.1).

Table III. Gray Scale Data

Brightness (ft-L)	Positive Half Pulse Width--μsec		
	Measurement Location		
	Center	Left Side	Lower Right
0.05	16	17.5	17.6
0.1	16.2	18	18
0.2	16.5	18.5	18.3
0.5	17	19	19
1.0	19	20	21
1.5	23	24	24
1.7	28.5	27	27
2.0	33	33	33

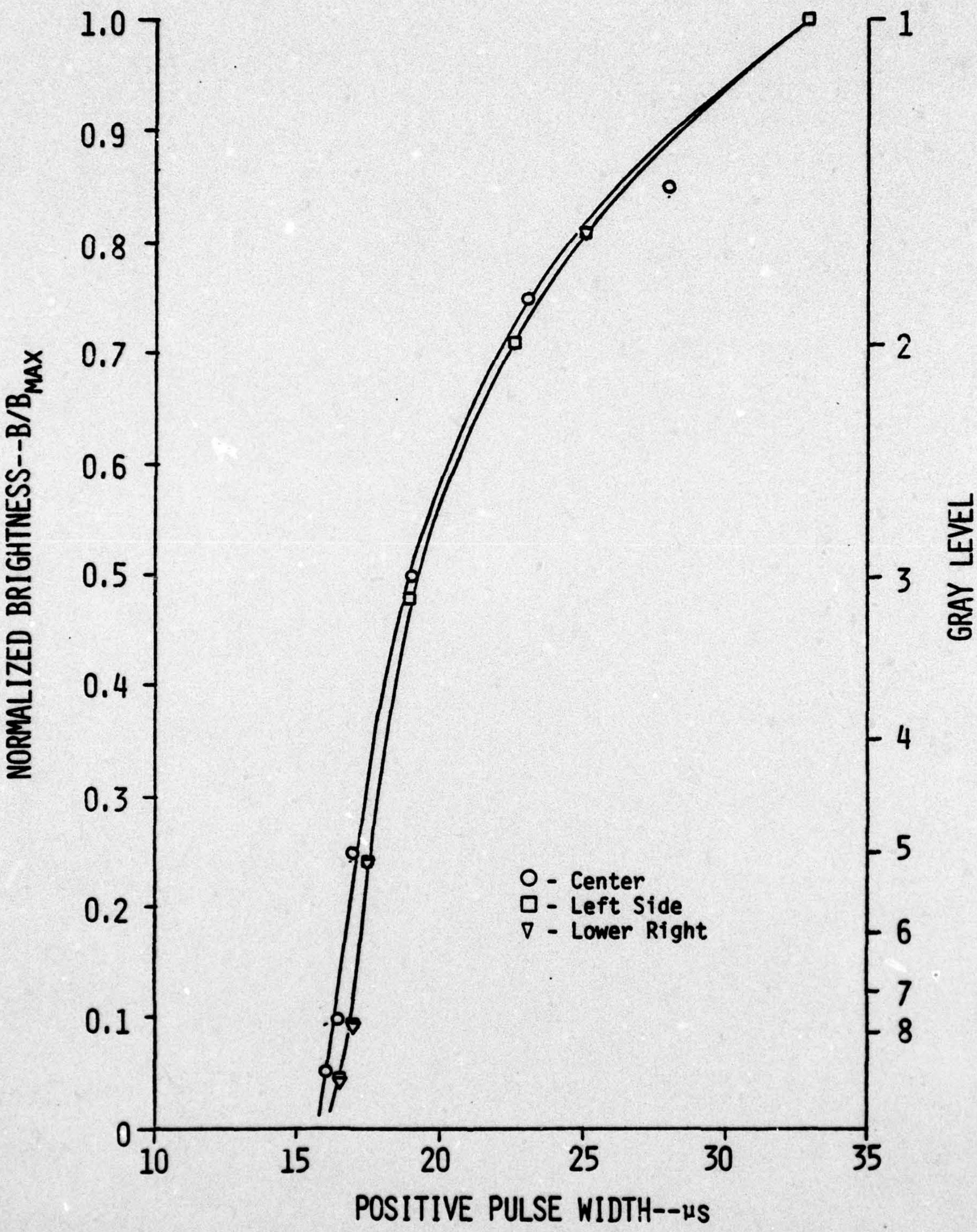


Fig. 11 Gray scale vs positive half pulse width--0.2% duty cycle excitation, No. 1027-2

A third contributor to background illumination is scattered light within the phosphor itself (halo effect). This is particularly evident in a micro-contrast measurement. A micro-contrast measurement was made on a 100×100 matrix array. A group of 20 lines was energized to full brightness. The brightness was then measured from a spot 21.4 microns in diameter. The measuring spot was moved away from the edge of the group of lighted lines. Table IV indicates the ratio of the brightness at the center of the edge line (B_{max}) to the measured brightness for several positions away from the lighted area. The ratio B_{max}/B is also the contrast ratio. At a distance of 5 elements away (0.010") the contrast ratio is 29:1. The micro-contrast could be improved considerably through use of a black metal electrode so that reflected light within the emitter is absorbed at the electrode. The black electrode would also reduce the emitted light by approximately 50% since emitted light propagating toward the electrode would be absorbed rather than reflected. The data of Table IV shows that a contrast ratio of 11.6:1 is possible one cell away from the lighted line. Eight shades of gray require a contrast ratio of at least 11.3:1. Therefore, based on these measurements, it appears that at least eight shades of gray are available on a micro-basis as limited by optical scattering, electrical cross talk and capability for electrical modulation.

A fourth contributor to background illumination is scattered and reflected ambient light. In the case where the ambient light is not controlled, the black metal electrode structure can considerably reduce this factor. For instance, a diffuse optical reflection of 0.8% has been measured on large-area electrode emitters produced recently. Alternatively, a completely transparent display is possible (see 5.7).

Table IV. Optical Halo Measurement--Contrast Ratio vs Distance from Lighted Line Matrix No. 12087

B_{max}/B	Distance from Center of Line (0.001")
1.0	0
2.9	1
11.6	2
19.3	3
29	10

Currently, a driver system is being fabricated such that 10 bars (10 lines/bar) will be excited to 10 different levels of intensity so that the above data can be substantiated on a macro scale.

5.6 Time Response

The rise and decay characteristic of display number 12087 was measured using the setup of Fig. 9. Figure 5 illustrates the rise and decay time characteristics. The rise time (10%-90%) is 50 μsec. The decay time (10%-90%) is 2.9 μsec. Therefore, image lag and smear when operated at 30 frames per second is not a problem.

5.7 Ambient Reflection

The device as fabricated utilized aluminum rear electrodes. Therefore, in an uncontrolled light ambient, considerable light is reflected from those electrodes. A diffuse reflectance of 30% was measured using a Gamma Model 191A Microreflectometer. The incident light was 45% to the substrate and the reflected light was measured normal to the substrate. For a reflective

display the diffuse reflectance could be reduced at most to 0.8% through use of a black metal rear electrode array. Since the black electrode absorbs emitted light as well, the available light to the observer would be reduced by 50% assuming an isotropic emitter.

Alternatively, transparent InO electrodes could be used in place of aluminum so that incident light would be transmitted directly through the display structure. Again, 50% of the emitted light would be lost to the observer due to the isotropic nature of the emitted light. In order to simulate the emitter structure without rear aluminum electrodes, the specular reflection was measured for a sample without a rear cover glass in an area free of aluminum electrodes. In addition, a glass cover slide coated on one side with an anti-reflection coating (HEA) was optically bonded to the viewing side of the emitter. The near normal (10°) specular reflection for this composite structure was 1.1%. A similar measurement on the aluminum electroded area yields a specular reflection of 4.4% which is below the 5% maximum specified as a goal. In a final device the rear cover glass would be coated with HEA coating on both sides as well. Therefore, it is reasonable that a normal ambient reflection well below the 5% maximum specified as a goal would be achievable for a "see-through" display if transparent rear InO electrodes were used in place of the existing aluminum electrodes.

6.0 CONCLUSIONS AND RECOMMENDATIONS

Experimental results obtained under this program indicate that TV-quality image display devices with at least 500 lines per resolution are directly attainable using thin film deposition techniques and photolithographic etching procedures.

In order to realize a solid-state, compact TV imaging system, several further developments are necessary:

1. Develop full 500×500 pixel panel with one-inch-square active display surface
2. Determine optimum interconnect techniques for interfacing display surface with drive electronics
3. Demonstrate TV scanning circuitry for 500×500 display

The existing display material is adequate where the required average display brightness is under 7 ft-L. For display brightness requirements of several hundred ft-L, optimization of a memory effect present in certain thin film emitters could provide high brightness (> 100 ft-L) under low duty cycle operation.

7.0 REFERENCES

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